Shallow Scattering Layer (SSL): Emergence Behaviors of Coastal Macrofauna

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LONG-TERM GOALS

Our long-term goals are to understand — to an extent that allows quantitative prediction — important interactions among acoustic propagation, marine organisms, particles (including sediments), solutes and moving fluids. The reason for these goals is to allow us to solve interesting forward and inverse problems in the marine environment.

OBJECTIVES

The objectives of this work are to develop a predictive understanding of emergence by coastal macrofauna in one region. By emergence we mean leaving the seabed to become part of the plankton or nekton, which typically occurs at night. In high-frequency acoustic records, this emergence appears as a "shallow scattering layer" that typically leaves the seabed after dusk and returns before dawn. Emergence and re-entry in shallow water appear to represent an evolutionary solution that avoids visual predation analogously with oceanic "deep scattering layers." In the coastal zone, the water is simply too shallow to provide a holoplanktonic solution.

The region selected for this work is midcoast Maine in the vicinity of the Darling Marine Center, which is located on the lower Damariscotta River. The region was chosen for its diversity of estuarine and coastal environments, including a range of optical properties in river and coastal waters.

APPROACH

The approach has three phases, and we are completing the second. The first was is a survey of the Damariscotta, Sheepscot and Kennebec estuaries for the presence and identity of emergent macrofauna. The second phase, nearing completion, entails collection of acoustic data to afford temporal and spatial resolution of the phenomenon in a region of strong emergence behavior, the mid-estuary Damariscotta. Last year's trapping results led us to believe that the emergence would be strongly modulated by the tides as well as by irradiance. The last phase entails identifying environmental cues that allow prediction of the occurrence and character of emergence events.

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WORK COMPLETED

We completed an initial regional survey, based on over 90 emergence-trap samples. On the basis of number and diversity of emergent fauna and for logistics we selected the mid-estuary Damariscotta as the preferred site for the second phase. We have continued to collect emergence-trap samples several times per week to maintain a record of sizes and identities of emergers, in part for acoustic inversion. More importantly, we have now collected TAPS-6 (Tracor Acoustic Profiling System with 6 frequencies from 265 kHz to 3 MHz; manufactured by BAE SYSTEMS, Inc.) data from mid June through mid September 2001, largely accompanied by ADCP profiles. The data are "gappy" because of punctuated problems with corrosion and electrical components, but we have many series long enough for powerful time-series analysis. Although all of our data are upward looking from a bottom-deployed frame, we have varied the angle of the beam relative to the vertical to trade off horizontal and vertical resolution.

RESULTS

The results show far more complex patterns than we had anticipated and reveal clear modulation by tides and light. One is the anticipated nightly emergence that is evident throughout our records, although its strength clearly varies with time and size category of emergers (Fig. 1A-D). A second pattern, seen most strongly during new moon in July, is of *twice* daily emergence synchronized with the tides (Fig. 1C, D). Fewer large individuals tend to emerge during the daytime events. In the new-moon series (Fig. 1C, D), the daytime emergence was dominated by large cyclopoid copepods. During the waning moon (Fig. 1A, B), there is also some evidence of daytime emergence events centered on the same tidal phase as the night-time emergence, but in this case the phase of highest abundance of emergers is at slack low. We are using time series analysis and other methods to mine this rich data set in order to set up explicit hypotheses to test during the next field season.

We also have documented through gut contents and laboratory feeding experiments that there are several steps of the food web involved in this migration. The mysids that we have focused on eat copepods that also emerge. The mysids (mostly *Neomysis americana)* in turn are eaten by decapod shrimp that also emerge *(Crangon)* and by fishes. We are interested in how organisms of different sizes differ in the phasing of their migrations, possibly in response to predation by other migrators.

Our prior data from West Sound, Orcas Island, Washington, show very little tidal modulation of emergence events (Kringel, Jumars and Holliday, in manuscript) and a single, nocturnal event each day, but tidal currents at that site are an order of magnitude weaker than in the Damariscotta River at the Darling Center. The pattern we display for the new moon is consistent with the results of Kimmerer *et al.* (1998) for the planktonic phases of mysids in the San Franciso Bay estuary. In their study *Neomysis mercedis* and *Acanthomysis* sp. appeared in the plankton during the night, and their planktonic abundances were highest during incoming tides.

IMPACT/APPLICATION

We have not found a shallow-water site yet where emergence after dusk does not appear in high-frequency acoustic records (*c.* 300 kHz). Sites include a 60-m Eel River station as part of Strataform, a 20-m West Sound, Orcas Island site, a Panama City site (DRI program), and now these Maine coastal sites. An obvious implication is that the acoustic environment will also be time varying. Our current results show that the time variation has a tidal as well as a diurnal component, yielding complicated patterns as the tides change over the month. During the last phase of this work, we hope to find relatively simple, quantitative predictors that allow us to predict the timing and magnitude of the migrations.

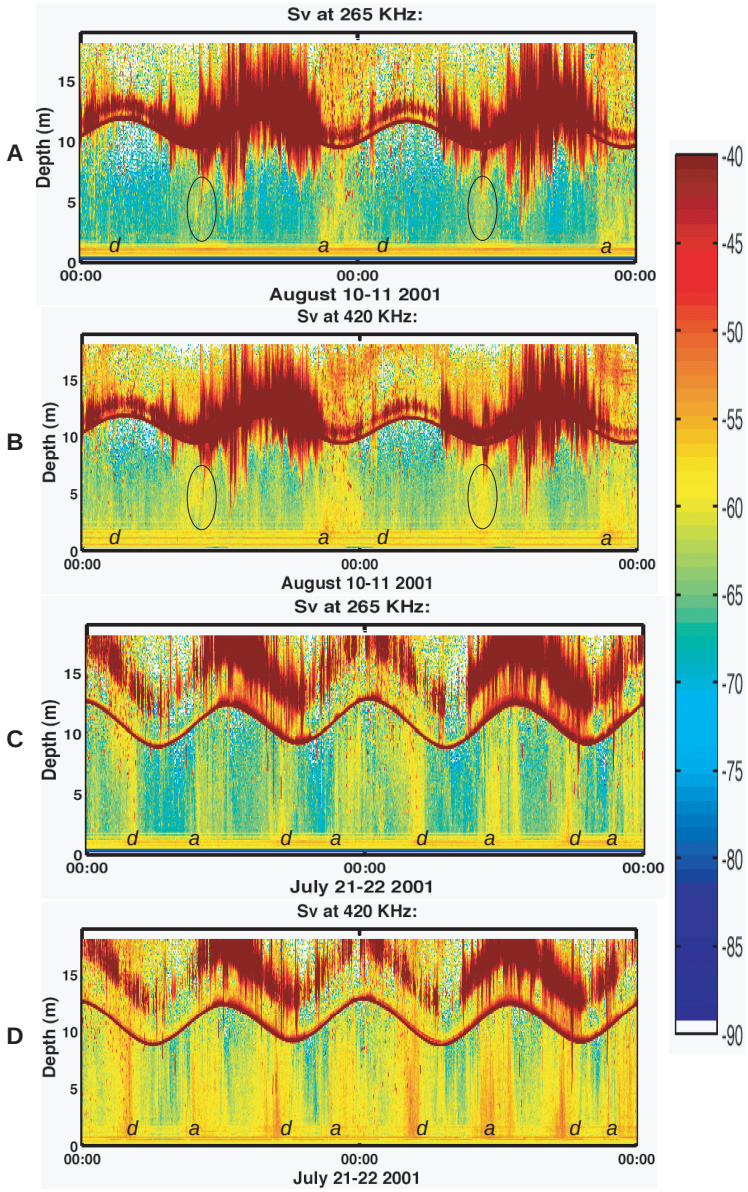

Figure 1. Two two-day time series of volume reverberation, S_v, at the two lowest of TAPS-6 frequencies (265 and 420 kHz). [A and B are simpler to interpret and were taken in August 2001, six days after the full moon, with TAPS-6 facing upward at 90ß to the seabed. The solid red line is the first reflection off the sea surface; the fuzzier band above probably encompasses reflections first off the bottom and then off the sea surface. The broad bands of high backscatter near the surface during daylight are schools of juvenile menhaden that disperse offshore at night but congregate at the surface near the shore during daylight for several weeks in Maine estuaries. Lower-case a and d indicate apparent ascents and descents, respectively. Ovals enclose times of apparent daylight emergence events. C and D show a series taken with TAPS-6 mounted at an angle of about 47ß to the seabed. The sharp reflects a direct path from TAPS-6 to the sea surface and back, outside the main beam, and so is still a useful indicator of the tides and water depth. The broader, less regular band above is the main beam s reflection from the water surface. It is broadest in the daytime because of the sea breeze that roughens the sea surface and also injects some bubbles through wave action. The regularity of the emergence pattern and its repetition with each tidal cycle, with low volume reverberation only at low slack, are stunning and contrast sharply with the pattern seen in the other two-day segment of data. These two data time series share in common a principal nighttime emergence echoed at the same tidal phase during daylight.

RELATED PROJECTS

This project is related to some components of the ONR DRI on High-Frequency Sound Interaction in Ocean Sediments (coordinated by Eric Thorsos of the Applied Physics Laboratory of the University of Washington). Evolving details can be found at <http://www.apl.washington.edu/hfsa-dri/Program/prog.html>.

Chris Jones of APL (N00014-00-1-0034) and Pete Jumars of the University of Maine (N00014-00-1-0035) are developing a cluster of instruments that allow experimental testing in convenient field sites of the putative effects of organisms whose field abundances can be manipulated. The concept is of a Portable Acoustic Laboratory (PAL) that can be deployed wherever there is a source of power and a data cable for download. In this way mechanisms can be investigated without waiting for an expensive field experiment to be fielded. The system currently has 300- and 120-kHz transducers to ensonify the sediments. One future target of this system may be the effects of emergent animals.

REFERENCES

Kimmerer, W.J., J.R. Burau, and W.A. Bennett. 1998 Tidally oriented vertical migration and position maintenance of zooplankton in a temperate estuary. *Limnology and Oceanography* **43:** 1697-1709

PUBLICATIONS

Kringel, K., P.A. Jumars and D.V. Holliday. A shallow scattering layer: high-resolution acoustic analysis of nocturnal vertical migration from the seabed. This manuscript is in preparation for submission to *Limnology and Oceanography* and will be posted at the url noted on the front page of this document when it is submitted.